APPENDIX A
HYDROLOGY AND FLOOD SERIES ANALYSIS

A.1 GENERAL HYDROLOGY

The watershed area upstream of Milltown Dam encompasses 5,984 square miles (3,829,760 acres), with elevations ranging from 3,218 feet at the Milltown Dam powerhouse to over 8,000 feet at both the Blackfoot River (BFR) and Clark Fork River (CFR) watershed divides. The CFR watershed is located west of the Continental Divide with most of the headwater streams originating along the Continental Divide. The BFR sub-watershed has relatively high mean annual precipitation ranging from 16 inches at the confluence with the CFR to 60 inches at the watershed divide (USDA Soil Conservation Service, 1990). The CFR sub-watershed has a lower mean annual precipitation ranging from 14 inches near Milltown Dam to 50 inches at the divide (USDA Soil Conservation Service, 1990). A majority of the precipitation in both watersheds occurs as snow that typically melts between April and June producing snowmelt runoff dominated hydrographs.

A.1.1 USGS Streamflow Gaging Stations

The USGS maintains and operates two streamflow gaging stations on the CFR and one on the BFR in the vicinity of the project area. The gaging stations provide real-time as well as historical information including annual flood peaks and mean daily discharge. The CFR stations are located approximately 5.8 valley miles upstream of Milltown Dam near Turah Bridge and approximately 2.8 river miles downstream of Milltown Dam near Hell's Gate Canyon upstream of the City of Missoula. The BFR station is located near Bonner, Montana approximately 6.4 miles northeast of the junction of State Highway 20 and old U.S. Highway 10 in Bonner, Montana. Table A-1 provides a list of the USGS gaging stations and associated years of record.

Table A-1. List of USGS gaging stations and years of record used to calculate the flood series for the CFR and BFR.

USGS Station No.	USGS Station Name	Years of Record
12334550	CFR at Turah Bridge near Bonner	21
12340500	CFR above Missoula	76
12340000	BFR near Bonner	73

A.1.2 Average Mean Daily Discharge

USGS gaging stations provide historical flow information for the BFR and CFR both upstream and downstream of the project area. Mean daily discharge values were reviewed to evaluate the timing, magnitude, and duration of peak and base flow discharges. In addition to providing important data for channel design, this information was used to forecast stream flow conditions that will likely be experienced during the implementation phase of this project.

The annual hydrograph of both rivers generally exhibit one peak flow period that occurs in May or June in response to snowmelt runoff. Snow pack characteristics, air temperature, and periodic rain events influence the timing and duration of spring runoff.
The annual hydrograph of the BFR is slightly regulated by Nevada Creek Reservoir and is affected by the appropriation of surface water for the irrigation of approximately 20,000 acres. Similarly, the CFR above Milltown Dam is somewhat regulated by the Warm Springs Ponds on Silver Bow Creek near Anaconda and Georgetown Lake on Flint Creek and is affected by the appropriation of surface water for the irrigation of approximately 100,000 acres. Discharge on the CFR above Milltown Dam is also regulated with diurnal fluctuations and is affected by the appropriation of surface water for the irrigation of approximately 120,000 acres.

Based on data available for the periods of record, the BFR typically flows less than 600 cfs from September through March with baseflow (discharge less than 600 cfs) discharge occurring from January through early March (Figure 1-1). Discharge typically exceeds 5,000 cfs from late May through mid-June with peak flows occurring in early June. The CFR at Turah Bridge typically flows less than 1,000 cfs from mid July through March and experiences baseflow (discharge less than 700 cfs) conditions from early August through early October, and from mid December to mid January. Flows typically exceed 2,000 cfs from early May through late June with peak flows occurring in early June (Figure A-1). The CFR above Missoula (downstream of Milltown Dam near East Missoula) typically flows less than 2,000 cfs from August through March with baseflow conditions (discharge less than 1,500 cfs) from mid August through early October, and from early December through February. Flows typically exceed 8,000 cfs from mid-May through late June with the highest flow typically occurring during the first week of June (Figure 1-1). Low flow conditions in the CFR in August and September are partially attributed to surface water appropriations and diversions for a variety of beneficial uses.

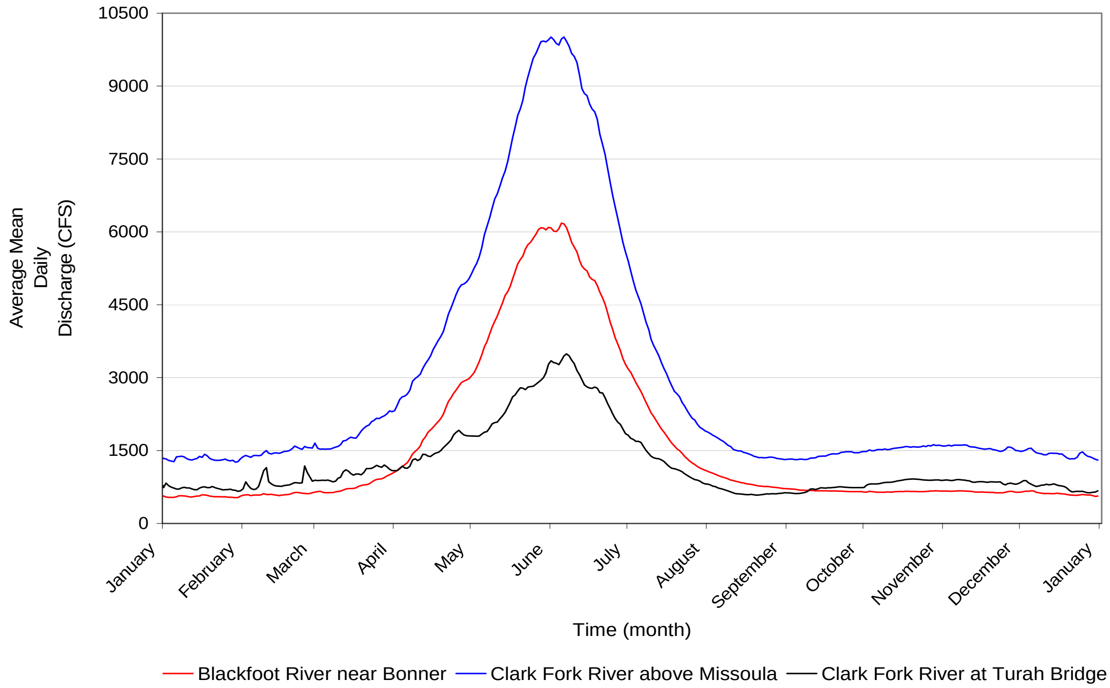

Figure A-1. Average mean daily discharge (in cubic feet/second) for the BFR near Bonner, CFR above Missoula, and CFR at Turah Bridge based on USGS historical streamflow gaging data.

A.1.3 Flood Histories

The CFRand BFR have experienced major floods over the past century, a majority of which are reflected in the USGS historical streamflow gaging records. In general, most floods were driven by rain-on-snow and rain-on-snowmelt events that produced events of significant magnitude and duration.

The largest flood of record on the CFR occurred in June 1908 in response to over 33 consecutive days of rain-on-snowmelt. The flood was estimated at 48,100 cfs and was greater than a 500 year event based on the updated flood frequency curve for the CFR gage above Missoula. Approximately 6,600,000 cubic yards of mine tailings and processing wastes from upstream mining operations were entrained by the CFR and its tributaries during this event. To alleviate hydrostatic pressure at Milltown Dam, operators dynamited the southern section of the structure to pass the flood waters. More recent flood events of hydrologic significance occurred in 1948, 1953, 1964, 1975 and 1981. Table A-2 provides a brief flood history for the CFR, including year, rank, and associated discharge and recurrence interval.

Table A-2. Flood history of the CFR above Missoula based on USGS gaging records.

Year	Rank	Discharge (cfs)	Recurrence Interval (yrs)
1908	1	48,100	500
1975	2	30,800	76
1964	3	30,500	38
1981	4	28,900	25
1948	5	28,800	19
1953	6	27,200	15
1997	7	26,400	13
1972	8	26,000	11
1976	9	24,800	10
1947	10	22,000	8

The BFR flood history is summarized in Table A-3, including year, rank, and associated discharge and recurrence interval. As noted, the 1964 event of 18,000 cfs was the highest magnitude flood recorded for the BFR and equated to an estimated recurrence interval of 73 years.

Table A-3. Flood history of the BFR near Bonner based on USGS gaging records.

Year	Rank	Discharge (cfs)	Recurrence Interval (yrs)
1964	1	18,000	73
1953	2	17,700	37
1899	3	17,200	24
1975	4	16,400	18
1997	5	15,800	15
1972	6	15,300	12
1948	7	15,200	10
1976	8	13,800	9
1947	9	12,800	8
1900	10	12,600	7

A.2.0 FLOOD SERIES ANALYSIS

This section presents updated flood magnitude and frequency data for the CFR and BFR USGS streamflow gaging stations for recurrence intervals of 2, 10, 25, 50, 100 and 500 years. Three gaging stations were analyzed including the CFR above Missoula (USGS Gage No. 12340500), CFR at Turah (USGS Gage No. 1233455), and BFR near Bonner (USGS Gage No. 12340000).

A.2.1 Flood Series Analysis Methods

Flood magnitudes for selected recurrence intervals were determined for the CFR and BFR from a flood frequency curve using the log-Pearson Type III distribution method as outlined in Bulletin #17B Guidelines for Determining Flood Flow Frequency (U.S. Department of the Interior Geological Survey, 1982). The USGS analyzed flood frequency for the CFR at Turah and BFR near Bonner through water year 1998 using methods outlined in *Methods for Estimating Flood Frequency in Montana Based on Data through Water Year 1998* (Parrett and Johnson, 2004). To account for the period 1998-2004, Environmental Management Consultants Corporation (EMC^2) conducted an additional analysis, extending the periods of record for the CFR at Turah and BFR near Bonner gaging stations to 19 and 70 years, respectively (EMC^2, July 13, 2004 technical memorandum). The six additional years of data decreased the 100-year flood estimate for the CFR at Turah Bridge by 1,700 cfs and did not significantly change the USGS analysis completed for the BFR near Bonner (EMC^2, July 13, 2004 technical memorandum). Flood magnitudes for selected recurrence intervals for the CFR above Missoula (downstream of Milltown Dam) were analyzed in 2005 by the USGS (C. Parrett, USGS, unpublished data).

A.2.2 Flood Series Analysis Results

Flood series analysis results are summarized in Table A-4 and displayed in Figures A-2, A-3 and A-4.

Table A-4. Log-Pearson Type III flood frequency analysis results.

USGS Station	Recurrence Interval (yrs)					
	Q_2	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}
CFR at Turah Bridge	4,600	9,700	12,600	14,700	16,900	22,100
BFR near Bonner	8,670	14,600	17,300	19,200	21,000	24,900
CFR above Missoula	14,580	25,680	30,780	34,370	37,770	45,150

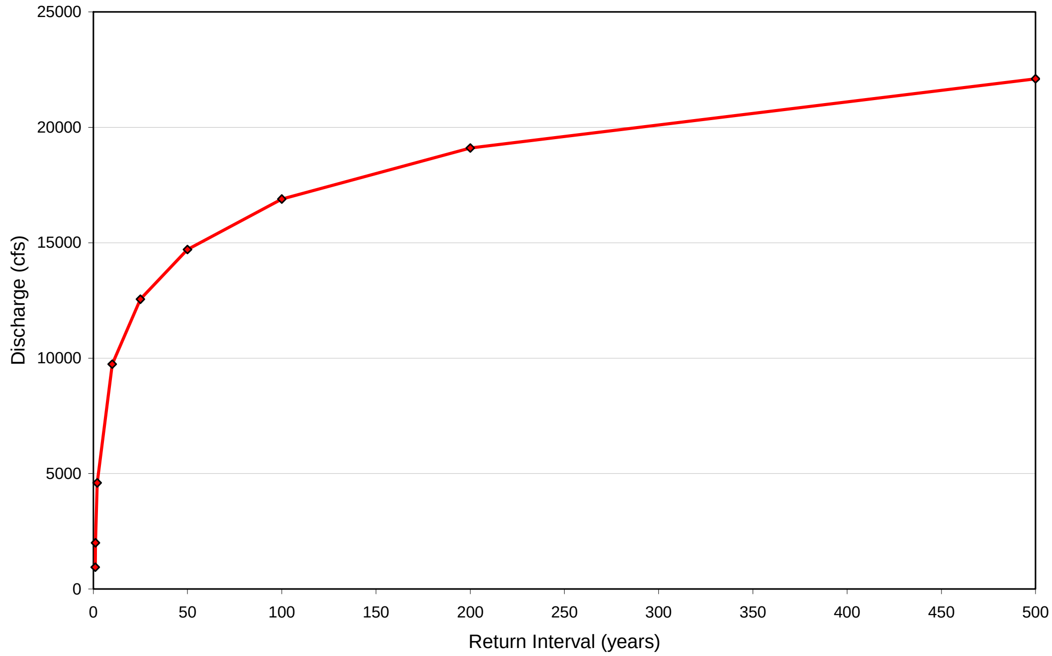

Figure A-2. Flood frequency analysis for the CFR at Turah Bridge near Bonner, MT through Water Year 2004 (EMC^2).

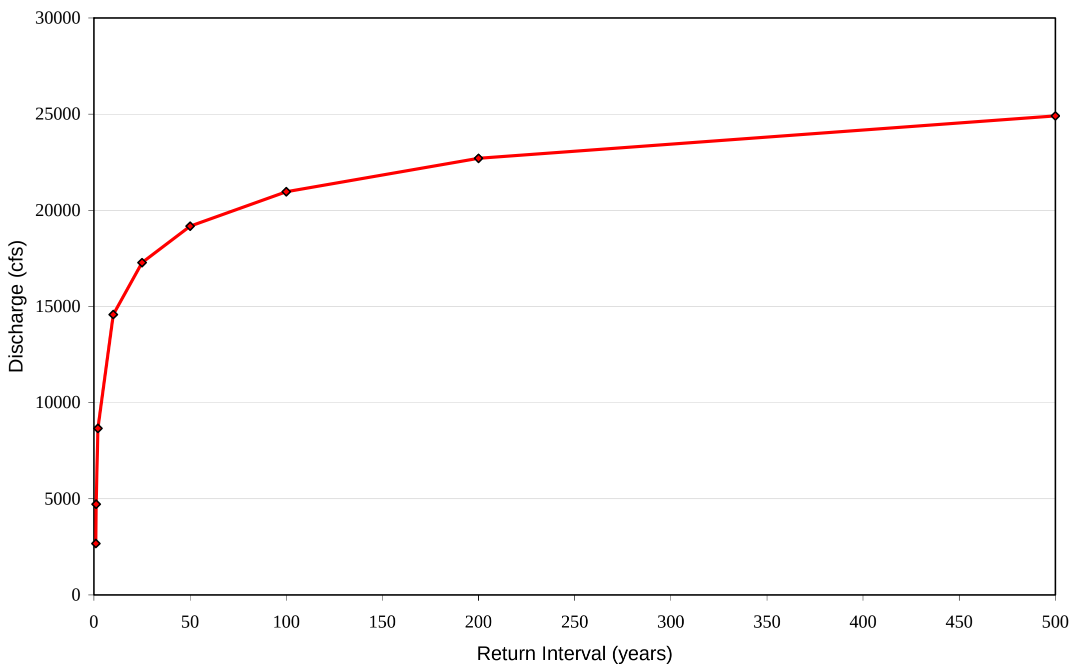

Figure A-3. Flood frequency analysis for the BFR near Bonner, MT through water year 2004 (EMC^2).

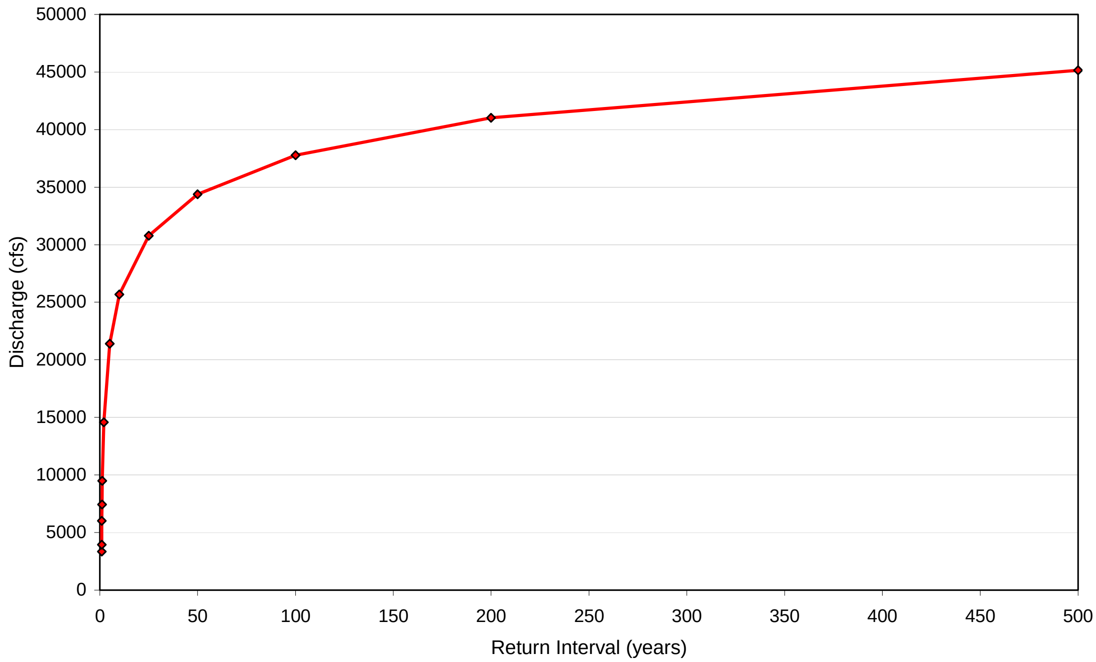

Figure A-4. Flood frequency analysis for the CFR above Missoula, MT through water year 2004 (C. Parrett, USGS, unpublished data).

A.3.0 CHANNEL FORMING AND BANKFULL DISCHARGE ANALYSIS

This section presents estimates of the channel forming discharge and associated recurrence intervals for the CFRand BFR. The channel-forming or dominant discharge is often used as the representative value for channel design (Shields et al., 2003) and is associated with the discharge that dominates channel form and process. Dunne and Leopold associated the channel forming discharge with a momentary maximum flow, which, on average, has a recurrence interval of 1.5-1.8 years as determined using a flood frequency analysis (Dunne and Leopold, 1978). For the purposes of this discussion, the channel-forming discharge is considered to be morphological bankfull (Charlton et al., 1978; Andres, 1984; Hey and Thorne, 1986).

A.3.1 Bankfull Discharge Methods

Two approaches were used to determine bankfull discharge for the BFR and CFR upstream of Milltown Dam: 1) analysis of flood frequency using historical streamflow gaging records; and 2) field calibration of bankfull discharge at the respective USGS gaging stations.

Method 1: Return Interval Discharge
The first method assumed that the channel forming discharge would approximate a flood recurrence interval of approximately 1.5 years. This assumption is consistent with results from a detailed USGS study for western Montana that investigated the bankfull recurrence interval discharge for 41 gaged sites (USGS Scientific Investigations Report 2004-5263, 2004). The study reported a median recurrence interval value of 1.5 years (range 1.0 to 4.4. years) for western Montana streams, which is similar to results reported from other studies (Rosgen, 1996; Moody and Odem, 1999; Castro and Jackson, 2001; and Cinotto, 2003). $Q_{1.5}$ results were

derived from the updated log-Pearson Type III frequency analyses completed for the gaging stations.

Method 2: Field Calibration
The second method included field calibration of bankfull discharge at the USGS gaging stations. Prior to field survey, discharge rating curves and hydraulic geometry relationship were developed from USGS 9-207 forms (summary of stream discharge notes) to estimate bankfull channel dimensions. At each gaging station, bankfull, water surface, thalweg and channel-distance data were surveyed. Data was processed in RIVERMorph version 3.1 (RIVERMorph LLC, 2005). Best-fit lines were plotted through the bankfull stage data and the gage height associated with bankfull discharge was derived. The discharge for each gaging station was then plotted on the updated flood frequency curve to determine the recurrence interval for the associated bankfull discharge.

A.3.2 Bankfull Discharge Results

Method 1: Return Interval
Results for bankfull discharge determined with the return interval discharge method are summarized in Table A-5. As noted, the estimated discharges for the CFR at Turah, BFR near Bonner, and CFR were 3,004 cfs, 6,059 cfs, and 9,892 cfs, respectively. This method assumed a return interval of 1.5 years.

Table A-5. Gage height (GH), dominant discharge (Q), and unit discharge expressed as cubic feet/second per square mile (CSM) results applying the return interval discharge method (RI=1.5 yrs).

USGS Station	GH (ft)	Q (cfs)	Drainage Area (mi^2)	CSM
CFR at Turah	5.02	3,004	3,641	0.83
BFR near Bonner	6.24	6,059	2,290	2.65
CFR above Missoula	6.53	9,892	5,999	1.78

Method 2: Field Calibration Method
Results of the field calibration method are summarized in Table A-6. The estimated discharges for the CFR at Turah, BFR near Bonner, and CFR above Missoula are 3,443 cfs, 6,156 cfs, and 10,418 cfs, respectively. The discharge values for the BFR near Bonner and CFR above Missoula gages are within 1.6 and 2.5 percent of the predicted values derived using the return interval method, respectively. Results for the CFR at Turah deviate by as much as 15 percent from the return interval method. Possible explanations for this include the relatively short period of record for the Turah gage, survey error associated with determining bankfull indicators due to observed channel instabilities associated with the Turah Bridge, and the flood of 1997 which effectively reset the hydraulic geometry relationships and rating curve for the gaging station.

Table A-6. Gage height (GH), dominant discharge (Q), and recurrence interval (RI) applying the field calibration method for the CFR at Turah, BFR near Bonner, and CFR above Missoula USGS gages.

USGS Station	GH (ft)	Q (cfs)	CSM	RI (yrs)
CFR at Turah	5.44	3,443	0.95	1.77
BFR near Bonner	6.21	6,156	2.69	1.54
CFR above Missoula	6.75	10,418	1.73	1.62

A.4.0 SUMMARY AND SELECTED DISCHARGES

This section presented the results of an updated flood series and bankfull discharge analysis for the CFRand BFR. Flood magnitudes for selected recurrence intervals were determined from a flood frequency curve using the log-Pearson Type III distribution method as outlined in Bulletin #17B Guidelines for Determining Flood Flow Frequency (U.S. Department of the Interior Geological Survey, 1982). Two approaches were used to determine bankfull discharge for the BFR and CFR upstream of Milltown Dam: analysis of flood frequency using historical streamflow gaging records, and field calibration of bankfull discharge at the USGS gaging stations.

The selected bankfull and flood magnitudes for selected recurrence intervals are presented in Table A-7. The selected flood magnitudes are based on the results of the updated flood frequency analyses completed by EMC^2 and the USGS. The field calibration results were derived from morphological bankfull features at the respective gaging stations and were therefore selected as the more accurate estimates of the channel-forming discharge. For the CFR at Turah Bridge near Bonner, the two results were averaged. Table A-7 presents the selected bankfull and flood flow values for the project area. Values were rounded to the nearest 100 cfs.

Table A-7. Selected bankfull (Q_{bf}) and flood flow values (cfs) for the CFR at Turah, BFR near Bonner, and CFR above Missoula USGS gages.

USGS Station	Recurrence Interval (yrs)						
	Q_{bf}	Q_2	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{500}
CFR at Turah	3,200	4,600	9,700	12,600	14,700	16,900	22,100
BFR near Bonner	6,200	8,670	14,600	17,300	19,200	21,000	24,900
CFR above Missoula	10,400	14,600	25,700	30,800	34,400	37,800	45,200